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The issues of life extension of seismic isolation system of circular tanks for storage of liquefied petroleum gases

Tsyss V.G.[a]*, Sergaeva M.Yu.[a]

[a]*Omsk State Technical University, 11, Mira Pr., Omsk 644050, Russian Federation*

Abstract

The aim is to determine the possibility of extending the life of rubber-metal dampeners of seismic isolation of spherical tanks for the storage of liquefied petroleum gas. There is offered a technique including accelerated aging dampeners for extended life, accelerated life tests and validation of their basic functional characteristics: creep, strength and stiffness. An example of application of the proposed method showing the possibility of extending the life of dampeners of spherical tanks seismic isolation up to 25 years was determined.

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Keywords: lifetime, rubber-metal dampener, model of operation, failure criterion, the measure of damages, the accelerated life test

1. Introduction

In the operation of spherical tanks on rubber-metal dampeners included in the system of seismic isolation, the following factors affect:

- constant static load on the weight of the tank;
- dynamic load due to variations in the depreciable buildings from seismic or vibration exposure;
- thermal influence of the ambient air.

The static load of the spherical tank weight causes primarily creep and static fatigue and seismic action (vibration) loads the cause of dynamic fatigue, which ultimately leads to a decrease in design efficiency. It is now known that the efficiency of rubber-metal dampeners is mainly determined by the fatigue mechanism caused during creep, fatigue, and changes in their performance.

* Corresponding author.
E-mail address: mjsergaewa@mail.ru

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Full service life of the dampeners is determined mainly by two performance factors: dynamic and temperature, which are represented by amplitude-frequency and time-temperature models of operation. The combination of amplitude and thermal shock models operation usually is rather arbitrary because in actual combinations of amplitudes and temperature effects are random. Therefore, it is expected that all combinations of modes of amplitude-frequency and temperature patterns of operation are equally probable, which allows to construct a general model of amplitude-temperature operation of the dampeners.

Since the life of the spherical tanks is 25-30 years, there is an urgent task of extending the dampeners life included in the regulatory vibration system for over 10 years. However, the experience of operating dampeners, installed at the facilities operating in similar conditions, and the results of verification tests to assess the dampeners residual life exhaust 12-14 years, it points to the possibility of extending their useful life. This possibility is based on the analysis of conditions of storage, use, test results to determine the strength and cyclic basic functional characteristics

The aim of this work is to study the possibility of extending the life of rubber-metal dampener systems of seismic isolation of liquefied petroleum gas spherical storage tanks.

2. Study subject

The study subject is rubber-metal dampener consisting of rubber solid and two metal plates vulcanised thereto. Table 1 shows the amplitude dampener model operation, and Table 2 - Operating temperature model.

Table 1. Amplitude model of dampener operation.

Loading Block	The amplitude of displacement, mm	The number of cycles, n
1	4.0	$4 \cdot 10^3$
2	2.0	$3 \cdot 10^5$
3	1.0	$3 \cdot 10^6$
4	0.25	$9 \cdot 10^9$

Table 2. Operating temperature model.

Temperature range T,ºC	The average temperature in the range of T,ºC	Duration of operation γ,%
-5 ... 5	0	2
5 ... 25	15	50
25 ... 40	33	33
40 ... 60	50	10
60 ... 70	65	5

3. Methods

The criteria for allowable change in functional characteristics of the dampeners to the end of the operation are the following [1]:

- changes in stiffness;
- change in creep (absorber height);
- change in strength (discontinuity of the material).

Based on the operating experience of rubber-metal dampeners there can be taken following rejection criteria limits change of dampeners (Table 3):

- change in stiffness of up to 50% of the nominal value (with increasing stiffness up to 50% the efficiency of vibration isolation is reduced to 3.5 dB and if more than 50% - there is an unacceptable reduction of structural strength);
- static strength reduction of up to 30% from the initial, while maintaining the dampener continuity with the two bumps on the value of the freewheel;
- creep deformation of 10% from the rubber solid thickness in the direction of the array weight depreciating object that corresponds to a reduction of dampener height up to 1 ... 3 mm.

Table 3. Failure criteria and limit values.

The dampener failure type	Limit values
Changing in stiffness	50% from the nominal value
Changes in strength	30% from the initial value
Change in creep	10% from the initial height of the dampener

The general methodology of studies on extending the life of the dampeners includes a complex of works consisting of following steps [2]:

- Collection and analysis of information on the actual operating conditions of dampeners.
- Investigation of stress-strain state of dampeners.
- Clarification vibro loading modes and accelerated aging on the basis of information on the actual operating conditions of dampeners.
- Carrying out accelerated aging of dismantled dampeners for extending the service life.
- Carrying out accelerated life tests of aged dampeners according to the amplitude-frequency model of operation in the equivalent test mode.
- Check functional characteristics of the dampeners.
- Development of recommendations on the possibility of extending the life of the tested dampeners.

The developed methodology assumes that the mechanical stress on the dampeners is reproduced with accelerated life tests and temperature - holding their accelerated aging. At the same time to reduce the time of research, dampeners, dismantled with objects are subjected to accelerate aging for a renewable period of operation (in this case - from 10 to 25 years). At the end of the accelerated aging dampeners endurance tests are conducted on modes equivalent to lifetime considering prolonging the period of operation. In the final stage of the research there was carried out checking their basic functional characteristics - stiffness, creep, resistance.

For the mathematical description of the dampeners resource characteristics the equations were used according to the following [3]:

$$lgF_i = k \cdot lgN_i + lgF_0(D_i, T_i) \tag{1}$$

where F_i is the amplitude of the deformation; N_i is resource dampener; k is a factor of dampener fatigue curve; $lgF_0(D_i, T_i)$ is initial ordinate of the fatigue curve, depending on the measure of damages D_i and temperature T_i.
The magnitude of the damage measure D_i is determined in accordance with the formula

$$D_i(F_i) = \frac{n_i(F_i)}{10^{\frac{\lg F_i - B}{k}}} \sum_{j=1}^{s} \gamma_j 10^{\frac{k_T T_j}{k}} \tag{2}$$

where γ_j is relative duration of operation in the temperature range of the dampener; $n_i(F_i)$ is the number of cycles of deformation in the *j-th* temperature range of *i-th* mode of operation; k_T, B are the parameters of the equation; s is number of temperature ranges; T_j is operating temperature.

Assuming a linear value of $D_i(F_i)$ in time, based on the principle of linear summation of damages, the total measure of the damage with the dampener extends the service life equal to

$$D_{\Sigma}(F_i)=\sum_{j=1}^{S} D_i(F_i) \tag{3}$$

The dampener fracture point will meet the condition $D_{\Sigma}(F_i)\geq 1$.

An equivalent number of cycles of deformation dampener mode accelerated life testing with amplitude F_{ad} and the temperature T_{ad} was determined by the formula

$$n_{ad} = N \cdot D_{\Sigma}(F_i)$$

or

$$n_{ad} = 10^{\frac{lgF_{ad} - k_T(T_u - T)}{k}} \sum_{i=1}^{l} \frac{n_i}{10^{\frac{lgF_i}{k}}} \tag{4}$$

where n_{ad} is given the number of cycles of deformation modes of accelerated life tests; N_{ad} is the number of cycles of deformation calculated by equation (1) at an amplitude of accelerated life F_{ad}; T_u is test temperature; l - the number of loading conditions the dampener.

4. Results and discussion

The research was carried out in phases, according to the proposed procedure (see Section 3). After 10 years operation dampeners were tested for compliance with the operating model based on extending the service life of 15 years (total service life of 25 years). When the amplitude F_1=1 mm operating time was n_1=7.58·10^5 cycles (with an amplitude of F_2=2.5 mm operating time was n_2=7.58×10^5 cycles) that meets the requirements of the model operation (Table 4).

Table 4. The dampener model operating and calculation steps of damage.

F_i, mm	n_i, cycles	N_{np}, cycles	D_i
0.15	9.0·10^9	6.75·10^{11}	0.013
0.20	2.0·10^6	1.82·10^{11}	0.000
0.40	1.0·10^6	7.78·10^9	0.0001
0.60	6.0·10^5	1.24·10^9	0.0005
1.50	1.0·10^5	1.90·10^7	0.0053
2.50	5.0·10^4	1.85·10^6	0.0269
		D_{Σ}=0.0462	

The mode of accelerated life tests of dampeners corresponding to their operating model was based on extending the service life of 15 years shown in Table 5.

Table 5. Mode of accelerated life tests of dampeners corresponding model their operation in view of extending life of up to 25 years.

Test Mode	Value
The amplitude of deformation, mm	2.5
Frequency deformation Hz	0.5
The equivalent operating temperature, ^{c}	28.0
Limit the number of cycles of deformation at F=2.5 mm	1.85×10^{6}
The above number of cycles F=2.5 mm	8.58×10^{4}

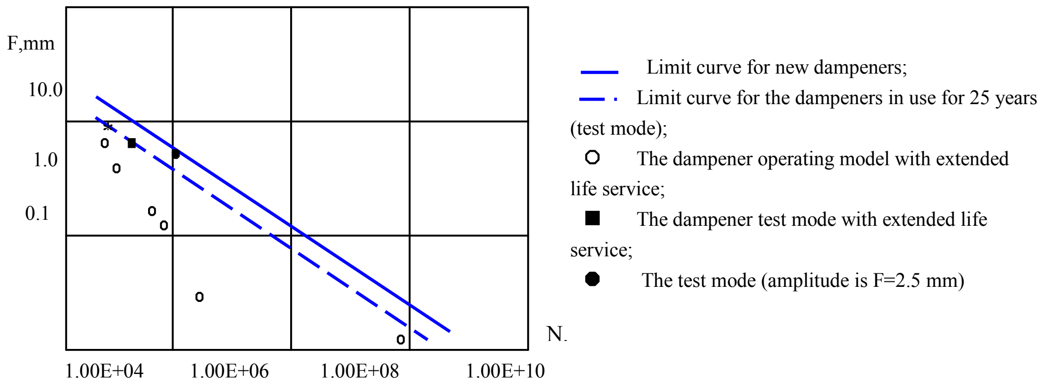
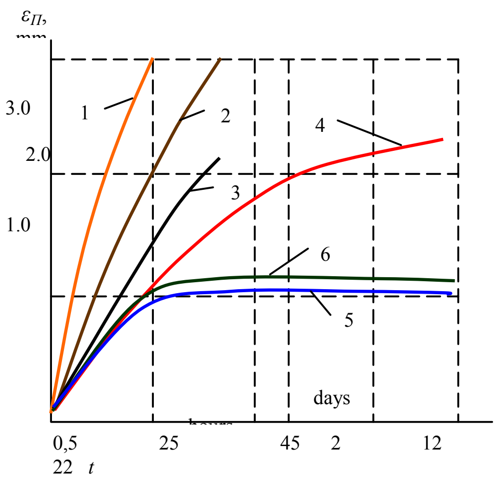


Fig. 1. Fatigue curves of new dampeners (Pos. 1) and in use for 25 years (Pos. 2).



The mode number	F, mm	f, Hz	T, °C
1	1.5	9.5	29
2	1.5	9.5	22
3	1.0	9.5	24
4	0.75	9.5	63
5	0.25	8.5	68
6	0.25	8.5	70

Fig. 2. Creep deformation (change in the height of dampeners) at different test modes.

Figure 3 shows a graph of changes in static dampener in free state and under load during aging (excessive heat). Figure 4 shows the results of variation of the static strength of the dampener under the load and ambient temperature.

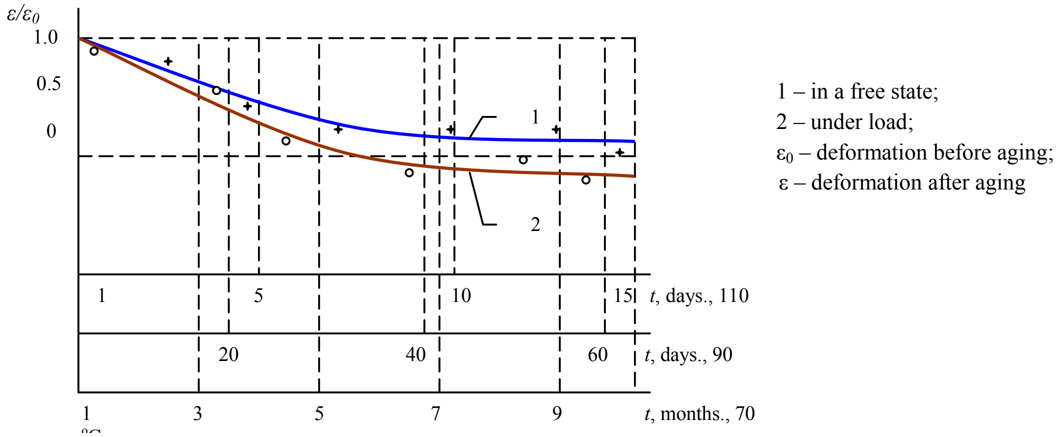


Fig. 3. Changing Static Dampener.

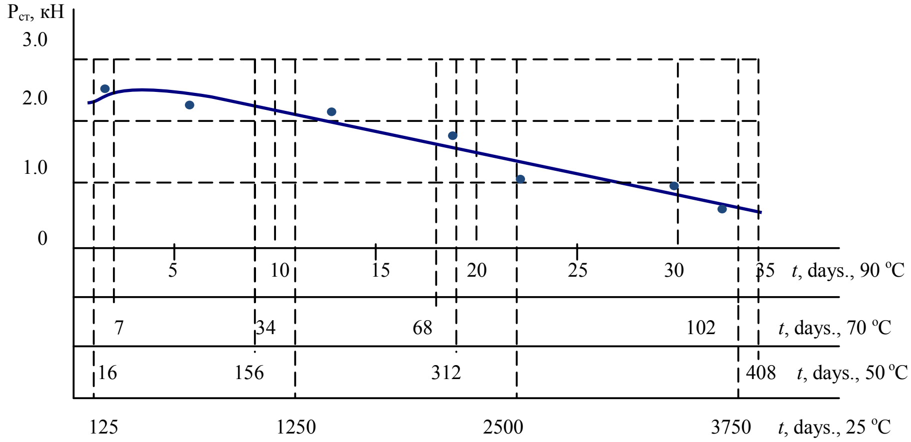


Fig. 4. Changing the static strength of the dampener at different ambient temperatures.

Thus, the results obtained in theoretical and experimental studies show that all of the major functional characteristics of rubber-metal dampeners (strength, stiffness, creep) after assuming that the operation prolongs the life is within acceptable limits.

5. Conclusion

The paper proposed a method of research, which includes the accelerated aging systems of seismic spherical tanks for a renewable term of service, the accelerated life tests of samples of aged dampeners and check their basic functional characteristics: strength, stiffness and creep.

There is considered a set of theoretical and experimental studies of rubber-metal dampeners showing that the dampeners subjected to accelerated aging, simulating an increase in their lifetime, extends the period of operation to ensure compliance with their basic functional characteristics of the technical documentation, and are within acceptable limits. This leads to the conclusion about the possibility of extending the life of the dampeners of seismic isolation of spherical tanks from standard 10 years to 25 years.

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